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IV

CLIMATIC RELATIONS OF THE TERTIARY AND QUATERNARY FAUNAS OF THE **CALIFORNIA REGION**

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Introduction.

The Tertiary and Quaternary formations of the West Coast of North America offer peculiar advantages for the study of climatic relations, for they are strung out along the coast from the equator to the boreal regions, and their faunas and floras may be compared with Recent faunas and floras in the same latitudes.

The Recent faunas of the West Coast, from the Galapagos Islands and Panama northward to Alaska, are well known, in publications and collections. The climatic conditions under which they live are known, and the range of species with reference to temperature of the water has been determined. By comparison with Recent faunas of the same region the climatic conditions (temperature) of a fossil fauna may be estimated, and the position of the isotherms plotted, with considerable accuracy. This accuracy naturally decreases as we go back in time, and the number of Recent species in the fossil fauna decreases to little or nothing. There are nearly 400 Recent species in the Quaternary faunas of the West Coast; of these nearly 100 range down into Pliocene, and over 50 into Miocene. No Recent species ranges back to Eocene, but most of the genera of that age are still represented somewhere in the world, and make possible accurate conclusions concerning the physical conditions of that time.

The writer has arranged at Stanford University an exhibition set of the marine faunas of the West Coast, from Eocene to the present, and from the equator to the Gulf of Alaska. This set corresponds to the accompanying correlation and climatic chart, the successive faunas being placed in parallel columns, so that each fossil fauna is in line with the corresponding Recent fauna of the same latitude.

The major geographic divisions used were as follows, from south to north: (1) Lower California and the Gulf of California; (2) Southern California; (3) Middle California; (4) Puget Sound; (5) Alaskan Gulf. The material in the exhibition set is necessarily not so detailed as that in the lists given below. And in these lists no attempt at completeness is made. Only those forms are listed that are really characteristic, that tell a definite story as to geographic range or geologic age.



CLIMATIC RELATIONS OF WEST COAST TERTIARY AND QUATERNARY

				С	LIMATIC RELATIC	ONS OF WEST COA	ST TERTIARY AND	QUATERNARY				
	RECENT	QUATER	RNARY	UPPER PI	LIOCENE	LOWER F	PLIOCENE	UPPER MIOCENE	LOWER	MIOCENE	OLIGOCENE	EOCENE
SUB-BOREAL	Alaska Min. temp. 44° B. Lat. 50°-55° N.	Cape None beds with Parter swift.	Doughs Island beds with boreal fauna St. Elins Alps beds with boreal fauna.	St. Elias Alps.?				Shomagir beds with mixture of temperat	i Islands If Puget Sound and c types:		Kenai flora warm-temperate,	Venericardia Planicosta beds subtropical,
COOL TEMPERATE	Pugot Sonne Nin, tempi 59 F Cape Menot/rine to Paget Sound Lat. 40°-50° N	ISOTHERM OF SO F	Vancouver Island Glacial beds with boreal fauna. Elk River beds of Cape Blanco with boreal fauna.		Marine buds of Pug tarapara		pe Mendocino with rate fama.	Empre beds with temperate fauna	Clallam beds with maxture of warn-temperate and subtropical types.		Astoria formation with subtropical fauna.	Tejon bods of Puret Sound with Palms and Venericardia planicosta.
TEMPERATE	Middle California Min. temp. 54° F. Lat. 35°-40° N. Pt. Conception to Cape Mendocino.		S. F. Persinsula beds with Pheet Sound fastin.	France Clerra lake both with cool-temperate faums and flora	Merced beds with cool-temperate fitamy Santa M mixture of north	th ern and southern	Etchegoin (Jacahtos) of Coast Ranges with subtropical fauna.	Santa Margarita- San Pablo beds with subtropical faunds;	Temblor beds with tropical fauna	Vagueros beds with tropical fauna.	San Lorenzo beds with Attıria.	Tejon beds with tropical fauna and flora.
WARM TEMPERATE	Southern California Min., temp., 62° F. Lat. 28°-35° N. Cerros Island to Pt. Conception.	Upper San Pedro beds with subtropical fauna.	Lower San Pedro bedawith Puget Sorthu fauna.	Santa Barbuta beda with Puget Sound Janua.	San Diego beds with warm-temperate fauna.	Fernando beds with mixture of warm-temperate and subtropical faunas.	Carrizo beds with tropical fauna.		Temblor beds with tropical fauna.	Vaqueros beds with tropical fauna.		Tejon beds with tropical fauna.
TROPICAL	Lower California Min, temp, 68 F. Lat. 0*28 N. West Codst up ty Cerros Jeland.	Galapagos Islands and Ecuador with tropical faunas.	Magdalena Bay with mixture of Californian and tropical faunas,		ISOTHERM OF 68° F.		Carrizo beds with tropical fauna,	Miocene	e of Lower Californ tropical fauna,	a with		Pt. St. Elena Ecuador, with Venericardia planicosta.
	Sub-boreal			Cool Temperate			Warm Temperate			Tropical		

We have thus a series of columnar sections from Eocene to the present, strung out from the equator to the Gulf of Alaska, at intervals of from 5° to 15°, giving good representatives of the Tertiary and Quaternary faunas of the tropical, subtropical, warm temperate, cold temperate, and subboreal zones; also for comparison, the Recent faunas of the same latitudes. We have also fossil floras of Eocene, Oligocene, Miocene and Pliocene, to check the results obtained from the faunas.

Quaternary faunas, as should be expected, are better represented than Tertiary, though this is true only on the West Coast. We have Quaternary faunas from Manta, Ecuador, and the Galapagos Islands under the equator; Magdalena Bay, Lower California, lat. 24° 30′ N.; San Ignacio Lagoon, lat. 27° N.; Cerros Island, lat. 28° N.; San Diego to Santa Barbara, southern California, lat. 33° to 34° 30′ N.; San Francisco Peninsula, lat. 37° 30′ N.; Cape Blanco, Oregon, lat. 43° N.; Victoria, Vancouver Island, lat. 48° N.; Douglas Island, Alaska, lat. 58° N.; and Cape Nome, lat. 64° N. These Quaternary faunas range from tropical to boreal, as they should, keeping pace with the Recent faunas, but showing in many cases great displacement of the isotherms, as compared with the present.

The Pliocene faunas, stretched out in the same way, show still greater displacement of the isotherms in some cases, which becomes more strongly marked in the Miocene. The extreme is reached in the Eocene, when a tropical temperature extended from the equator to Alaska, strongly contrasted with lower Quaternary, when a sub-boreal temperature extended down nearly to San Diego.

The constant fall of temperature from Eocene to lower Quaternary, and the temporary rise in the upper San Pedro, were not confined to the West Coast, being apparent also in the Atlantic and the Mediterranean regions. But the evidence of its great regularity is almost peculiar to western America.

It is important to know upon what basis a given fauna is assigned to a certain horizon, and also what genera or species are used as climatic criteria. Not all genera or species are equally characteristic, nor are they equally characteristic in different geographic zones. Cucullæa is an Eocene genus in

	MIOCENE	OLIGOCENE	EOCENE	
SUB-BOREAL	Mi	Kenai flora warm-temperate,	Veneticardia Planicosta beds subtropical.	
COOL TEMPERATE		Astoria formation with subtropical fauna.	Tejon beds of Pucet Sound with Palms and Venericardia planicosta	
TEMPERATE	M Vagueros beds with tropical fauna.	San Lorenzo beds with Aturia.	Tejon beds with tropical fauna and flora.	
WARM TEMPERATE	Sor Vaqueros beds Mi with L tropical fauna.		Tejon beds with tropical fauna.	
TROPICAL	Lea with Mi I		Pt. St. Elena Ecuador, with Venericardia planicosta.	



California, but is still living in the Indian Ocean region. Lyropecten is a Miocene group in middle California, survives into lower Pliocene in southern California, and is still living in Lower California. Miopleionia is an Oligocene genus in the Puget Sound region, but in middle California is characteristic of lower Pliocene.

The writer has prepared a table of diagnostic forms used as criteria in determining the age of West Coast formations. This table is given below. But since an important genus or species may be common in one geographic region and lacking in another, or may be characteristic of a certain horizon in one and of a different horizon in another region, still another table has been prepared, showing the climatic as well as geologic range of the important forms. This brings out especially well the differences in geologic range of the same species in different latitudes. In this table the occurrence of a form is registered with (+), and the absence of a form from a horizon in one province is registered with (0).

DIAGNOSTIC FORMS IN WEST COAST NEOZOIC FAUNAS.

EOCENE.

Many extinct genera: Strepsidura, Ficopsis, Perissolax; many genera now confined to the tropics: Avicula, Crassatellites, Cucullæa, giant Lima, Meretrix, giant Venericardia, Ancillaria, giant Conus, Cassis, Murex, Rimella, Strombus, Terebellum, Turbinella, Volutilithes, true Nautilus, spatangoid sea-urchins, and cidaroids (absence of all ammonites, Inoceramus, belemnites, Exogyra and Trigonia). No climatic zones, and faunas not yet provincial.

OLIGOCENE.

Survival of many Eocene genera, but appearance of more modern types; modern groups of Pecten, especially Chlamys; Spisula, Panopæa, Phacoides; modern groups of Veneridæ, especially Chione and Macrocallista; Agasoma, Dolium, Miopleionia, Priscofusus, Molopophorus, Strepsidura, Turcicula, Aturia. First appearance of modern species of Mollusca: Panopæa generosa, Macoma nasuta, Thracia trapezoidea,

Thyasira bisecta. Fewer tropical genera than in Eocene. Faunas already provincial, but climatic zones not yet definitely established.

MIOCENE.

Numerous Pecten: Lyropecten, Amusium, Patinopecten, Janira, Spondylus; Veneridæ abundant: Chione ancestral to modern groups, Amiantis, Dosinia, Tivela; giant Ostrea; giant Cardium; Pinna; Avicula; Agasoma, Astræa, giant Conus, Ficus, Mitra, Molopophorus, Miopleionia, Nassa, Oliva, Priscofusus, Purpura, Trophon, Turritella, Rapana, Astrodapsis, Clypeaster, Dendraster, Scutella. Disappearance in later Miocene of most of the tropical genera, and reduction in size of most of the remaining ones. Notable exception to this is the great increase in the size of the pectens and oysters, which are veritable giants. Few extinct genera: Molopophorus, Agasoma, Miopleionia, Astrodapsis. Climatic zones developed, but not sharply defined. Faunas distinctly provincial. Many modern species.

PLIOCENE.

Dwarf Venericardia, Arca, Cardium, Chione, Spisula, Patinopecten, Chlamys, Janira, Paphia; Fusus, Chrysodomus, Purpura, Nassa, Dendraster. Climatic zones already sharply defined in lower Pliocene, with Miopleionia, giant Chrysodomus, Buccinum, Volutopsius, and Patinopecten in northern California; and Lyropecten, Janira, abundant Chione, Dosinia, Ficus, Murex, and giant Conus in southern California. The Wildcat fauna of Humboldt County, California, was cold temperate, the Purisima of middle California was warm temperate, while the Fernando of southern California was subtropical, all contemporaneous.

Miopleionia and Astrodapsis are the only extinct genera, but there are many now extinct in the Californian province. More than half of the Pliocene species are still living.

QUATERNARY.

Fauna like the Recent, but with rapidly shifting climatic zones, northern species ranging southward in lower Pleistocene, and southern species ranging northward in upper Pleistocene. Few extinct species, but many extinct locally.

DERIVATION OF TERTIARY MARINE FAUNAS OF CALIFORNIA.

The marine faunas of Tertiary and Recent time on the coast of California must be either endemic or immigrants. There are certain persistent stocks that appear to give us a continuous line from Eocene time, but the great majority are unmistakeably immigrants. The regions from which they may have come are so limited in number and so characteristic in their faunas that it is comparatively easy to determine the kinship and probable origin of the successive faunas in the California province.

The Martinez Eocene has strong Oriental affinities, shown in: Ovula, Xenophora, and the Tudicla group. The Tejon Eocene, while having some Oriental survivors, such as Rimella, Terebellum and the Tudiela group, is clearly Caribbean in kinship, in proof of which may be cited the Venericardia planicosta fauna, which came in from the Atlantic region through the

Panama portal.

The Oligocene is decidedly Oriental, as shown by the incoming of *Voluta* (*Miopleionia*), *Dolium*, and Japanese types of *Nucula*. The incoming of these forms is accompanied by the advent of northern species: *Thyasira bisecta*, *Phacoides acutilineatus*. *Solemya*, and *Turcicula*.

The lower Miocene Vaqueros fauna retains some Oriental survivors, such as *Rapana*, but is, in the main, Caribbean in

kinship. The Lyropecten group is the most characteristic Caribbean element, having been present in that region already in Oligocene, and wholly lacking on the Pacific coast in that

epoch.

R. E. Dickerson* has shown that in lower Miocene time there was probably a connection between the Caribbean and the Pacific. This is borne out not only by the occurrence of

Lyropecten, but also by Dosinia and the giant oysters.

In the Temblor epoch of the lower Miocene there is no further suggestion of Caribbean immigration, although *Lyropecten* is still exceedingly abundant. There is, however, a suggestion of renewed Oriental immigration in the Pecten groups, *Pallium* and *Amusium*.

The upper Miocene faunas appear to be endemic, or descendants of those that preceded them, the only outside increments

^{*} Proc. Calif. Acad. Sci., 4th ser., vol. 7, p. 197, et seq.

being gradually increasing numbers of northern types such as Chrysodomus.

In the lower Pliocene there is a great influx of northern forms such as *Chrysodomus* and *Patinopecten*, accompanied by some Oriental elements such as *Haliotis*, and *Pallium*. These mingled in southern California with northward-moving species from the Panama fauna.

In upper Pliocene the tropical species are nearly all gone, and the fauna of Puget Sound has extended its sway southward to San Diego. The relationships of the lower San Pedro Pleistocene fauna are the same as those of the upper Pliocene, with the northern facies still more distinct.

The upper San Pedro fauna is southern in kinship, with many species now living only in the Panama region.

CLIMATIC RANGE OF WEST COAST TERTIARY FORMS

		Lower Miocene	Upper Miocene	Lower Pliocene	Upper Pliocene	Quaternary	Recent
PUGET SOUND Cape Mendocino to Vancouver Island.	Pecten caurinus. Dwarf Venericardia. Giant Chrysodomus. Miopleionia. Argobuccinum Phacoides annulatus Arca trilineata Gyrineum Giant Turritella Lyropecten Janira. Dosinia	: :+ : :+0000	:+++++0000	+:++++::0000		+++ :++ : :0000	+++ :++ ::0000
MIDDLE CALIFORNIA Pt. Conception to Cape Mendocino.	Dendraster gibbsi. Pecten caurinus Argobuccinum Giant Chrysodomus Dwarf Venericardia Phacoides annulatus Lyropecten Janira. Ficus Miopleionia Pecten healeyi Arca trilineata Astrodapsis Chione (gnidia group) Giant Turritella Dosinia Trophon.	::+++::+:+++	+::::++++::+++0++	++++++000+++0+0++	:::+++000:0::000:		:0000:00000:::::00000

	7						
		Lower Miocene	Upper Miocene	Lower Pliocene	Upper Pliocene	Quaternary	Recent
SOUTHERN CALIFORNIA	Pecten caurinus Argobuccinum Miopleionia Phacoides annulatus Dwarf Venericardia Ficus Giant Arca Lyropecten Janira. Pecten healeyi Trophon. Giant Turritella Chione (gnidia group) Trachycardium. Dosinia Astrodapsis. Dendraster gibbsi Clypeaster. Mellita.	::0::+:++:++:::		0 :0+:+++++ :0+++++++:	: 0+: +0+0++: +0000 :+0	++:++0++:+0++::++	00 :000000+ :+00+0 : :00
LOWER CALIFORNIA	Lyropecten Janira. Giant Arca Dosinia. Giant Turritella. Ficus Dendraster gibbsi. Chione (gnidia group). Clypeaster Mellita Encope. Astræidæ	+ : : : : : : : : : : : : : : : : : : :	++	+++::::+:++		+++++ :~+ : :+ :	+++++ :++++ :

It will be seen from the table, and the lists included in this paper, that Patinopecten (Pecten caurinus), dwarf Venericardia, giant Chrysodomus, Phacoides annulatus, and Miopleionia are northern types, appearing first in the northern region, making their way southward as the temperature was lowered, all reaching southern California in the lower Pliocene. Miopleionia perished there, but the others continued to live on until the present, holding out in their northern home, where the proper temperature for them still prevails.

On the other hand, giant Venericardia, giant Conus, giant Turritella, Chione of the gnidia group, Dosinia, Lyropecten and Ficus are southern, tropical, types. They doubtless appeared first in the south, but ranged far to the north in early Tertiary times. Giant Venericardia has found no dwelling place north of the tropics since Eocene; giant Turritella has

been confined to the torrid zone since lower Miocene; Ficus, Lyropecten, Janira and Astrodapsis retreated southward, and are found in southern California in the lower Pliocene, Fernando, where Astrodapsis became extinct. Ficus and Lyropecten retreated still further south, but the latter, along with Janira and Dosinia, reappears in the warm water upper San Pedro epoch. All these forms, with the exception of Astrodapsis, are still abundantly represented in the Gulf or Panama fauna, and Astrodapsis has there a very near relative in Clypeaster. These are only a few out of the many examples that might be brought up.

CLIMATIC DISTRIBUTION OF RECENT MARINE FAUNAS OF THE WEST COAST.

I. Alaskan Gulf (Gulf of Alaska to Vancouver Island, lat. 60°-50° N., min. temp. 44° F.). Astarte borealis Schum., Astarte alaskensis Dall, Cardium californiense Desh., Glycimeris septentrionalis Midd., Macoma middendorffi Dall, Mya truncata L., Pecten hastatus Sby., Pecten islandicus Sby., Peronidea lutea Gray, Serripes grænlandicus Gmel., Saxicava arctica L., Siliqua patula Dixon, Spisula alaskana Dall, Thyasira bisecta Con., Venericardia alaskana Dall, Venericardia crassidens B. & S., Bela harpa Dall, Beringius morchianus Dall, Beringius kennicotti Dall, Beringius crebricostatus Dall, Buccinum alcuticum Dall, Buccinum morchianum Fisch., Buccinum glaciale L., Chrysodomus amiantus Dall, Chrysodomus liratus Martyn, Chrysodomus magnus Dall, Natica pallida B. & S., Sipho halibrectus Dall, Tritonofusus halli Dall, Tritonofusus rectirostris Carp., Turris circinata Dall, Volutopsius castaneus Morch., Volutopsius kobelti Dall, Volutoharpa ampullacea Midd., Scutella parma Lam., Strongylocentrotus dræbachiensis Say.

The Alaskan Gulf fauna contains a large number of circumboreal species, some of which are also common to the North Atlantic.

II. Puget Sound (Vancouver Island to Cape Mendocino, lat. 50°-40° N., min. temp. 50° F.). Astarte compacta Carp., Glycimeris septentrionalis Midd., Kennerleya grandis Rv., Leda fossa Baird, Marcia kennerleyi Rv., Marcia subdiaphana Carp.,

Panomya ampla Dall, Panopea generosa Gld., Pecten caurinus Gld., Pecten hericeus Gould, Phacoides annulatus Rv., Saxidomus giganteus Desh., Siliqua nuttalli Con., Thracia trapezoidea Con., Thyasira bisecta Con., Venericardia ventricosa Gld., Amphissa corrugata Rv., Boreotrophon gracilis Perry, Boreotrophon stuarti Smith, Chrysodomus phæniceus Dall, Chrysodomus tabulatus Baird, Haliotis gigantea Chem., Natica clausa B. & S., Purpura foliata Martyn, Tritonofusus jordani Dall, Trichotropis cancellata Hds., Turris perversa Gabb.

The Puget Sound fauna contains a considerable number of circumboreal species, also several inhabitants of the Japanese coast that are not circumboreal. The influx of circumpolar species is probably going on now, but that from Japan certainly is not. All the species on the northwest coast that are common to Japan date back to Pliocene time, when the configuration of the coast-line, and the climate permitted free intermigration between the two regions.

III. Middle California (Cape Mendocino to Point Conception, lat. 40°-34° 30′ N., min temp. 54° F.). Cardium corbis Martyn, Pandora punctata Carp., Paphia staminea Con., Paphia tenerrima Carp., Macoma bodegensis Hds., Modiolus flabellatus Gld., Schizothærus nuttalli Con., Tivela crassatelloides Con., Yoldia cooperi Gabb, Bathytoma carpenteriana Gabb, Calliostoma canaliculatum Martyn, Cancellaria crawfordiana Dall, Chlorostoma montereyi Kien., Gyrineum californicum Hds., Lucapina crenulata Sby., Nassa fossata Gld., Nassa perpinguis Gld., Polinices lewisii Gld., Haliotis rufescens Swain, Dendraster excentricus Esch., Strongylocentrotus purpuratus Stimp.

There are few characteristic species confined to this province. The fauna is chiefly composed of northern species ranging southward, and southern species ranging northward.

IV. Southern California (Point Conception, California, to Cerros Island, Lower California, lat. 34° 30′ to 28° N., min. temp. 62° F.). Amiantis callosa Con., Arca multicostata Sby., Atrina oldroydi Dall, Cardium elatum Sby., Cardium quadrigenarium Sby., Chione succincta Val., Chione fluctifraga Sby., Metis alta Con., Pecten æquisulcatus Carp., Pecten diegensis Dall, Pecten hastatus Sby., Phacoides richthofeni Gabb, Spisula

hemphilli Dall, Semele decisa Con., Astræa undosa Wood, Conus californicus Hds., Crucibulum spinosum Sby., Cypræa spadicea Gray, Murex carpenteri Dall, Fusus barbarensis Trask, Gyrineum californicum Hds., Siphonalia kellettii Fbs., Trophon belcheri Hds., Trophon triangulatus Carp., Polinices recluzianus Desh., Strongylocentrotus franciscanus Ag.

V. Gulf of California (Cerros Island, Lower California, to Panama, lat. 28° to 8° 30' N., min temp. 68° F.). Arca grandis Sby., Arca multicostata Sby., Arca pacifica Sby., Arca tuberculosa Sby., Avicula peruviana Rv., Chione gnidia Sby., Chione neglecta Carp., Cardium procerum Sby., Codokia distinguenda Tryon, Crassatellites gibbosus Sby., Dosinia dunkeri Phil., Dosinia ponderosa Gray, Macrocallista aurantiaca Sby., Macrocallista squalida Sby., Mactra exoleta Gray, Margaritiphora fimbriata Dkr., Miltha childreni Gray, Mulinia pallida B. & S., Ostrea palmula Carp., Pecten circularis Sby., Pecten dentatus Sby., Pecten subnodosus Sby., Spondylus crassisquama Lam., Cassis tenuis Grav. Cassis abbreviata Lam., Cerithium gemmatum Hds., Conus fergusoni Sby., Conus princeps L., Conus purpurascens Brod., Cuma kiosquiformis Duclos, Cvpræa exanthema L., Dolium (Malea) ringens Swain., Eupleura muriciformis Brod., Fusus dupetithouarsi Kien., Ficus decussatus Wood, Macron æthiops Rv., Macron kellettii Hds., Mitra tristis Brod., Murex radix Lam., Oliva araneosa Lam., Oliva porphyria L., Oliva splendidula Sby., Purpura hæmostoma L., Strombus gracilior Sby., strombus granulatus Gray, Strombina lanceolata Sby., Terebra robusta Hds., Turritella goniostoma Val., Turbo fluctuosus Wood, Arbacia stellata Gray, Cidaris thouarsii Ag. & Desot., Encope californica Verrill, Encope grandis Ag., Encope micropora A. Ag., Mellita longifissa Mich., Clypeaster rotundus A. Ag., Hipponoe depressa Ag., Lovenia cordiformis Lutken, Pocillopora capitata Verrill, Porites compressa Verrill.

Fossil Faunas. QUATERNARY.

Manta, Ecuador, lat. 1° S., collected by B. Bryan. Arca pacifica Sby., Arca reversa Rv., Cardium consors B. & S., Cardium magnificum Desh., Cytherea multicostata Sby.,

Chama frondosa Brod., Carditamera affinis Brod., Chione amalthusia Phil., Dosinia ponderosa Gray, Dosinia dunkeri Phil., Glycimeris giganteus Rv., Glycimeris inequalis Sby., Macrocallista auriantiaca Sby., Margaritiphora fimbriata Dkr., Mulinia pallida B. & S., Ostrea chilensis Phil., Pecten circularis Sby., Spondylus crassisquama Lam., Venericardia cuvieri Brod., Bullaria adamsi Menke, Cerithium adustum Kien., Conus princeps L., Conus purpurascens Brod., Conus virgatus Rv., Cymia tectum Wood, Latirus castaneus Rv., Latirus ceratus Wood, Latirus varicosus Rv., Murex multicrispatus Dkr., Murex radix Gmel., Oliva peruviana Lam., Strombus gracilior Sby., Strombus granulatus Gray, Terebra robusta Hds., Thais crassa Bl., Turritella goniostoma Val., Turbo saxosus Wood, Uvanilla olivacea Wood, Vasum muricatum Born, Vitularia salebrosa King.

These species are all living now in the same region. The fauna is thoroughly tropical, and is probably very late Quaternary.

Galapagos Islands. This fauna evidently belongs to the older Quaternary, since it contains a number of extinct species. The fossils collected several years ago by Mr. W. H. Ochsner for the California Academy of Sciences are now under investigation by Dr. Dall. No displacement of the isotherms is indicated, and none could be expected under the equator.

Magdalena Bay, Lower California, lat. 24° 30' N. Collected by R. G. McGregor and E. Call Brown. Arca tuberculosa Sby., Cardium elatum Sby., Cardium consors B. & S., Chione neglecta Carp., Macrocallista squalida Sby., Metis alta Con., Mulinia pallida B. & S., Pecten circularis Sby., Pecten subnodosus Sby., Tapes grata Say, Tellina punica Born, Astræa undosa Wood, Cerithium adustum Kien, Cerithium gemmatum Hds., Cerithium ocellatum Hds., Cuma kiosquiformis Duclos, Conus princeps L., Conus purpurascens Brod., Eupleura muriciformis Brod., Macron æthiops Rv., Macron kellettii Hds., Murex festivus Hds., Oliva angulata Lam., Oliva araneosa Lam., Oliva porphyria L., Olivella biplicata Sby., Pleurotoma carpenteriana Gabb, Purpura hæmostoma L., Ranella californica Hds., Strombus gracilior Sby., Strombus granulatus Gray, Terebra robusta Hds., Terebra specillata Hds., Terebra var-

iegata Gray, Turbo fluctuosus Wood, Turritella goniostoma Val., Dendraster excentricus Esch., Encope micropora A. Ag.

This fauna is probably lower Quaternary, for while the species are all living, several are not known so far south, some not south of California. This probably shows a slight southward displacement of the isotherm; but the temperature was probably not lowered below 68° F.

The Quaternary fauna of San Ignacio Lagoon, lat. 27° N., collected by Henry Hemphill, is practically the same as that of Magdalena Bay. This is also true of that of Cerros Island, off Lower California, lat. 28° N., which is now the meeting place of the warm temperate fauna of California with that of the tropical Gulf of California.

Southern California (San Diego to Santa Barbara, lat. 33°–34° N.). The Quaternary of southern California is well known through the work of Ralph Arnold¹, under the name of the San Pedro formation. This formation has furnished a rich fauna of beautifully preserved forms, and the study of it has thrown much light upon the Quaternary history of the West Coast. Arnold divides the formation into two divisions: upper San Pedro and lower San Pedro.

Lower San Pedro. This phase is best developed at San Pedro, near Los Angeles, but is also found at Ventura and Santa Barbara. Important members of the fauna are: Macoma calcarea Gmel., Marcia subdiaphana Carp., Pecten caurinus Gld., Pecten hastatus Sby., Panopea generosa Gld., Phacoides annulatus Rv.. Venericardia babarensis Stearns, Amphissa corrugata Hds., Argobuccinum oregonense Redf., Boreotrophon gracilis Perry, Boreotrophon stuarti Smith, Chrysodomus tabulatus Baird, Natica clausa B. & S., Tritonofusus rectirostris Carp., Turris perversa Gabb, (all Recent species in the cold water of the Puget Sound region); and Pecten jordani Arnold, Crepidula princeps Con., Pisania fortis Carp., extinct species. Of the whole fauna about 90 per cent are living, though mostly not in the southern California waters. The fauna indicates a temperature of about 50° F., a displacement southward of the isotherms of 1500 miles, and a lowering of temperature of about 12° F., as com-

¹ Paleont. and Stratig. Marine Piocene and Pleistocene of San Pedro, California. <Mem. Calif. Acad. Sci., Vol. 3, 1903.

pared with the present. This epoch probably corresponds to the time of maximum glaciation of the continent. R. A. Daly² has estimated that the general lowering of temperature at the maximum glaciation was about 14° F., which agrees with the figure given.

Upper San Pedro. This fauna is best known at San Pedro. Dead Man Island, and Santa Barbara; the beds in which it occurs lie unconformably above the lower San Pedro, and consist of unconsolidated sands, gently tilted. The time interval between the two formations is not long, but long enough for the climate to have changed entirely, for the temperature to have risen from 12° F. below the present to about 4° F. above the present; long enough for the isotherm of 50° F. to have been pushed far to the north, and for that of about 66° F. to have invaded southern California. Among the important species of the upper San Pedro are: Amiantis callosa Con., Cardium elatum Sby., Chione succincta Val., Metis alta Con., Pecten æquisulcatus Carp., Pitaria newcombiana Dall. Astræa undosa Wood, Chorus belcheri Hds., Gyrineum californicum Hds., Siphonalia kellettii Hds., (all Recent species in southern California); and Cardium procerum Sby., Chione gnidia Sby., Chione neglecta Sby., Dosinia ponderosa Grav, Miltha childreni Gray, Mactra exoleta Gray, Mulinia gravi Dall, Pecten dentatus Sby., Pecten subnodosus Sby., Eupleura muriciformis Brod., Macron kellettii Hds., Nassa versicolor Adams. Mellita longifissa Mich. (all tropical species in Lower California or the Gulf of California): and Cancellaria tritonidea Gabb, Crepidula princeps Con. and Pisania fortis Carp., which are extinct.

The upper San Pedro is not post-Glacial, the number of extinct mollusca, about five per cent in a large fauna, being too great for that to be possible. It is probably interglacial. There was in Europe, after the second glaciation, a warm epoch in which the temperature of southern Europe was higher than that of the present. It may be that the upper San Pedro epoch corresponds to this. The cause of the rise was not local.

We have no way of measuring the time that has elapsed since the upper San Pedro, but it was long enough for about

² Glacial control theory of coral reefs. <Proc. Amer. Acad. Arts and Sci. Vol. 51, No. 4, (1915) p. 168.

five per cent of the fauna to have become extinct entirely, for all the tropical Mexican and Panama species to die out locally, and for the general temperature to be lowered by about 4° F.; also long enough for a considerable amount of deformation, terracing, and erosion to have taken place.

San Francisco Peninsula, lat. 37° 30′ N. The Pleistocene deposits of Seven Mile Beach, near San Francisco, contain a fauna very like that now living in the same region, with the exception of Natica clausa, which is not known south of Puget Sound. Further collecting would probably yield more northern species.

Elk River, Cape Blanco (southwest Oregon, lat. 42° 50' N.). In the raised beach are found: Kennerleya grandis Midd., Macoma middendorffi Dall, Mya truncata L., Pecten caurinus Gld., Saxidomus giganteus Desh., Spisula voyi Gabb, Venericardia ventricosa Gld., Amphissa corrugata Hds., Argobuccinum oregonense Redf., Bela harpa Dall, Bela tabulata Carp., Boreotrophon gracilis Perry, Boreotrophon stuarti Smith, Buccinum strigillatum Dall, Chrysodomus phæniceus Dall, Chrysodomus tabulatus Baird, Epitonium hindsi Carp., Natica clausa B. & S., Purpura foliata Gmel., Sipho halibrectus Dall, Solariella cidaris Adams, Trichotropis cancellata Hds., Tritonofusus rectirostris Dall, Turris perversa Gabb, (all northern or Puget Sound species), along with a considerable number of forms now living on the Oregon coast. This fauna indicates a temperature considerably lower than that now prevailing at Cape Blanco, and thus probably belongs to the lower San Pedro.

Arnold and Hannibal³ assign the Cape Blanco beds to the upper Pliocene, but the fauna listed by them is a mixture of Pliocene and Quaternary. Dall's interpretation of the geology of Cape Blanco⁴ was partly correct.

Vancouver Island (near Victoria, lat. 48° 30' N.). Astarte alaskensis Dall, Cardium comoxense Dall, Cardium decoratum Grew., Leda fossa Baird, Macoma calcarea Gmel., Macoma krausei Dall, Mya truncata L., Pecten islandicus Müller, Saxicava arctica L., Serripes grænlandicus Gmel., Natica clausa B. & S., Natica pallida B. & S.

⁸ Marine Tertiary Stratigraphy of the North Pacific Coast of America. <Proc. Amer. Phil. Soc. Vol. 52, No. 212, 1913, p. 595.

⁶ Bull. 196, U. S. Geol. Survey, (1902), p. 31.

This is a boreal fauna, indicating a temperature lower by several degrees than the present, and is probably Glacial in age.

Douglas Island (southern Alaska, lat. 58° N.). Astarte borealis Sch., Cardium ciliatum Fab., Cardium decoratum Grew., Leda fossa Baird, Macoma balthica L., Macoma calcarea Gmel., Mya truncata L., Pecten hericeus Gld. var. navarchus Dall, Saxicava arctica L., Venericardia stearnsi Dall, Chrysodomus liratus Martyn, Natica pallida B. & S., Hemithyris psittacea Gmel.

W. H. Dall⁵, who described this fauna, says that it indicates a temperature considerably colder than the present.

Cape Nome, lat. 64° N. In unconsolidated sands on intermediate beach, Center Creek, Cape Nome, Alaska. Macoma middendorffi Dall, Monia macroschisma Desh., Pecten swifti Bernh. This small fauna is interesting as well as important. Dall⁶ assigns it to Pliocene, but the material seen by the writer can only belong to the Quaternary. Also all Pliocene, north of middle California, indicates a lower temperature than the present. Pecten swifti now lives in the Japanese waters 1200 miles south, and eight degrees warmer than that of Cape Nome.

This is the only case where the warm water phase of the Quaternary is known in the far north, but farther search should yield many localities on both sides of the Pacific. It is to be expected that the Japan current would carry the warm water fauna farther to the north on the Siberian coast than it has been able to go on the American shore.

Mt. St. Elias. I. C. Russell⁷ mentions the occurrence of marine beds of Pliocene age uplifted to the height of 5000 feet on the slopes of Mt. St. Elias. The fauna is said to consist of Recent species. No lists of this fauna have been given, but in a later paper A. H. Brooks⁸ says that these beds probably belong to the Quaternary.

PLIOCENE.

There is at present much confusion in the correlation and nomenclature of the Pliocene formations on the West Coast. This comes from the disconnected occurrence of the beds, their

Harriman Expedition. Neozoic invertebrate fossils, p. 120, Vol. 4, 1904.
 On climatic conditions at Cape Nome, etc. Amer. Jour. Sci. Vol. 173 (1907) p.

^{457.}Expedition to Mt. St. Elias. < Nat. Geograph. Mag. Vol. 3, 1891, pp. 170-175.

Geog. and Geol. of Alaska, Prof. Paper No. 45, U. S. Geol. Survey. 1906, p. 295.

varying lithology, and the great variety of rapidly changing climatic conditions under which they were laid down.

Equal confusion has existed concerning the climatic relations of the Pliocene of the West Coast, some having regarded it as indicating a cold climate and others treating it as uniformly warm. W. H. Dall⁹ makes a statement that the Pliocene on the West Coast was warmer than the Miocene. The Pliocene of San Diego was certainly warmer than the upper Miocene of Oregon and Washington; but if the Pliocene is compared with the Miocene of its own latitude it will be seen, without exception, to have been cooler.

There is much need of revision of the data concerning the Pliocene of California, where the greater part of the work has been done. The writer has therefore prepared detailed tables of this region, showing the present state of our knowledge, and giving the results of researches carried on in the last few years. These results are not final, for this is, at present, the firing line in West Coast stratigraphy.

The Pliocene appears to have been a time of considerable intermigration between Japan and western America, but all the Oriental types that came over were northern forms. No species characteristic of warm water came from the southern Orient since lower Miocene time.

⁹ On climatic conditions at Cape Nome, etc. < Amer. Jour. Sci. Vol. 173, (1907), p. 457.

Marine Pliocene Formations of the West Coast of North America

Alaska	Mt. St. Elias beds? (Probably Quaternary)						
Puget Sound			Pliocene beds of Olympic Peninsula with Purisima fauna	XX.F			
Oregon		Beds of Cape Blanco and Fossil Rock					
Northern California		Crescent City beds	Wildcat formation of Eel River with cold water fauna				
Middle California	Santa Clara lake beds	Merced beds of San Francisco Peninsula	Purisima formation of San Francisco Peninsula	Jacalitos- Etchegoin beds of San Joaquin Valley and Coast Ranges			
Point Conception			Santa Maria beds of Fugler's Point in Santa Maria oil fields	"Lower Fernando" beds of Santa Maria			
Southern California	Beds of Santa Barbara and Dead Man Island	Beds of San Diego, Pacific Beach, Camulos Ranch and Los Angeles	Fernando of Elsmere Canyon, Puente Hills, and 3d St. tunnel, Los Angeles	Carrizo beds of Imperia and San Diego Counties			
Lower California				Carrizo beds of Cerros Island			
	Santa Barbara	San Diego	Fernando	Carrizo			
LOWER UPPER							

INTERREGIONAL CORRELATION TABLE OF PLIOCENE FAUNAS

UPPER	ITALY	NORTHERN EUROPE	CALIFORNIA
	Sicilian- (Villafranchian) appearance of Boreal species	Weyburn Crag of Norfolk. Norwich Crag. Boreal faunas.	Santa Barbara zone of southern California, with cold temperate fauna.
	Astian warm temperate fauna, with some tropical left-overs, and the beginning of the influx of northern types.	Red Crag of England, and Scaldesian of Belgium, Coralline Crag of England.	San Diego Beds of southern California and Merced of northern California.
LOWER	Plaisancian with subtropical species, left over from the Indian Ocean fauna.	Diestian beds of Antwerp, and Lenhamian of England.	Fernando beds of southern California, and Purisima beds of northern California.
LO	Messenian- (Zanclean), with fauna largely tropical. (Miocene?)	Wanting.	Carrizo of southern California and Jacalitos-Etchegoin of middle California.

The Messenian has 83% extinct and the fauna is largely tropical. The Plaisancian still has Indian Ocean species, and many remnants of the tropical fauna, like the Fernando. The Astian is more temperate, and the Coralline Crag, like the Purisima, begins to show influx of northern types. In the Sicilian, and Norfolk Crag, the boreal types have completely replaced the southern.

PLIOCENE FAUNAS OF THE WEST COAST.

Olympic Peninsula (coast of Washington, lat. 48° N.). Collections made by R. Arnold, A. B. Reagan, and H. Hannibal, have yielded: Cardium meekanum Gabb, Chione securis Shum, Macoma calcarea Gmel., Marcia oregonensis Con., Panopea generosa Gld., Pecten caurinus Gld., Phacoides annulatus Rv., Spisula voyi Gabb, Thyasira bisecta Con., Argobuccinum oregonense Redf., Astræa inequalis Martyn, Chrysodomus imperialis Dall, Chrysodomus tabulatus Baird, Gyrineum marshalli Reagan, Natica clausa B. & S., Purpura foliata Martyn, Turris perversa Gabb.

This is a Puget Sound fauna, indicating a temperature of about 50° F., the same as at present, showing no displacement of the isotherms. The age of this fauna is probably the same as that of the Purisima of middle California, upper part of lower Pliocene. About half of the species are extinct, and those still living are confined to cold water.

Cape Blanco (mouth of Elk River, southern Oregon, lat. 42° 50′ N.). Macoma astori Dall, Marcia gibbosa Gabb, Mya truncata L., Macoma nasuta Con., Paphia staminea Con., Pecten caurinus Gld., Spisula albaria Con., Thyasira bisecta Con., Yoldia strigata Dall, Polinices lewisii Gld., Dendraster interlineatus Stimp. This fauna is probably of Merced age, lower part of upper Pliocene.

Wildcat Fauna (Eel River, Humboldt Co., California, north of Cape Mendocino, lat. 40° 30′ N.). Collections made by W. M. Gabb, W. S. Monroe, W. G. Cooper, B. Martin, and H. Hannibal have yielded: Arca trilineata Con., Cardium meekanum Gabb, Chione securis Shum., Glycimeris coalingensis Sen., Macoma calcarea Gmel., Marcia oregonensis Con., Panomya ampla Dall, Paphia staleyi Gabb, Pecten caurinus Gld., Pecten dilleri Dall, Phacoides annulatus Rv., Serribes grænlandicus Gmel., Spisula albaria Con., Spisula voyi Gabb, Schizothærus pajaroanus Con., Thracia trapezoidea Con., Thyasira bisecta Con., Venericardia castor Dall, Zirphæa gabbi Tryon, Boreotrophon fleernerensis Martin, Buccinum saundersi Martin, Chrysodomus eurckaensis Martin, Chrysodomus imperialis Dall, Chrysodomus liratus Martyn, Chrysodomus lawsoni Martin, Chrysodomus purisimaensis Martin, Chrysodomus scotiaensis Martin, Chrysodomus postplanatus Dall, Gyrineum marshalli Reagan, Haliotis rufescens Swains., Linatella pacifica Dall, Miopleionia oregonensis Dall, Nassa moraniana Martin, Natica clausa B. & S., Polinices galianoi Dall. Tritonofusus fortunasensis Martin, Dendraster interlineatus Stimp., Dendraster oregonensis Clark.

This fauna has been variously assigned, to upper Miocene, and to the Merced horizon of the Pliocene. Its real age is that of the Purisima of middle California, and the true Fernando of southern California, upper part of lower Pliocene. It is probable, however, that in the thick section of the Wildcat formation the uppermost beds may overlap with the Merced, and the low-

est beds may belong to the age of the Etchegoin-Jacalitos fauna of middle California.

The Wildcat fauna belongs to the Puget Sound province, which then extended southward to Cape Mendocino, as it does now, and indicates a temperature of about 50° F. min. It lacks all the southern, warm-water, types, such as giant Arca, Dosinia, Chione gnidia group, Janira, Pecten healeyi, Pecten oweni, Lyropecten. It was the southern limit of the northern forms: Macoma calcarea, Pecten caurinus, Pecten dilleri, Natica clausa, Buccinum, Haliotis and Volutopsius. It is especially characterized by the large number of giant Chrysodomus, and by the first appearance of the oriental Haliotis in the California waters.

Cape Mendocino played the part, which now falls to Pt. Conception, as the dividing line between the warm-water and the cold-water faunas. This was the time of greatest differentiation of climatic zones on the Californian coast. The cold-water zone extended down to Cape Mendocino, and the warm-temperate zone pressed northward nearly to the same place. There was thus some telescoping of the isotherms, with the middle Californian province obliterated. This fact has made difficult the correlation of the Pliocene of northern California with that of the southern part of the state, and has resulted in faunas of the same age having been assigned to very different parts of the geologic column.

Merced (San Francisco Peninsula, south of San Francisco, lat. 37° 30′ N.).

Collections by W. M. Gabb, G. H. Ashley, B. Martin, H. Hannibal, and many others have yielded: Arca trilineata Con., Cardium meekanum Gabb, Cardium quadrigenarium Con., Chione securis Shum., Marcia gibbosa Gabb, Mya japonica Jay, Pandora grandis Dall, Paphia staleyi Gabb, Phacoides annulatus Rv., Saxidomus giganteus Desh., Schizothærus pajaroanus Con., Spisula albaria Con., Zirphæa gabbi Tryon, Chrysodomus stantoni Arn., Chrysodomus (tabulatus) var. colmaensis Martin, Crepidula princeps Con., Nassa moraniana Martin, Natica clausa B. & S., Pisania fortis Carp., Dendraster interlineatus Stimp.

This fauna is more northern in character than the underlying Purisima, agreeing more nearly in character with the older and more northerly Wildcat formation. Of the entire fauna about 35% are extinct and 65% living. It is commonly regarded as upper Pliocene, but belongs to the older horizon of that division. The temperature of the sea in which the Merced beds were laid down was probably about 50° F., instead of 55° F. at present.

Purisima (Half Moon Bay, on the San Francisco Peninsula, lat. 37° N.). Arca trilineata Con., Cardium meekanum Gabb, Chione securis Shum., Glycimeris coalingensis Arn., Macoma calcarea Gmel., Macoma middendorffi Dall, Marcia oregonensis Con., Mya truncata L., Panomya ampla Dall, Panopea generosa Gld. Paphia stalevi Gabb, Pecten purisimaensis Arn., Peronidea lutea Gray, Phacoides annulatus Rv., Schizothærus pajaroanus Con., Spisula albaria Con., Spisula vovi Gabb, Thracia trapezoidea Con., Yoldia cooperi Gabb, Zirphea gabbi Tryon, Argobuccinum oregonense Redf., Bathytoma carpenteriana Gabb, Chrysodomus colmaensis Martin, Chrysodomus imperialis Dall, Chrysodomus liratus Martyn, Chrysodomus portolaensis Arn., Chrysodomus burisimaensis Martyn, Chrysodomus stantoni Arn., Chrysodomus tabulatus Baird, Crepidula princeps Con., Gyrineum marshalli Reagan, Miopleionia oregonensis Dall, Nassa moraniana Martin, Natica clausa B. & S., Natica draconis Dall, Natica lewisii Gld., Dendraster interlineatus Stimp. (all northern types, or characteristic of this latitude); and: Arca canalis Con., Chione elsmerensis Eng., Dosinia ponderosa Gray, Pecten healeyi Arn., Pecten nutteri Arn., Pecten purisimaensis Arn., Pecten oweni Arn., Dendraster ashleyi Arn., Dendraster perrini Weaver, (all southern types).

This fauna shows a mixture of southern and northern types, with the latter predominating, the giant *Chrysodomus*, especially, indicating cooler water. *Dosinia ponderosa*, *Arca canalis*, and *Chione clsmerensis* indicate warm water. The temperature was probably a little warmer than the present, approximately 60° F., since northern forms can and do range southward by increasing their depth, while southern forms can not range north of their normal temperature.

Of the whole fauna 46% are extinct, and 54% living.

Santa Clara lake beds. These freshwater beds are known at many localities around the Santa Clara Valley, south of San Francisco. They contain a small fauna of bivalves and gastro-

pods mostly living now in the Klamath Lakes in southern Oregon; also a small flora of species now living in the Klamath Mountains of northern California. This region is more than 300 miles to the north, and about 4000 feet higher than the ancient Santa Clara lakes. It is safe to assume that the temperature of the land and the sea during the Santa Clara epoch was as cool as it now is in the latitude of Cape Mendocino.

The Santa Clara beds overlie the Merced, and are the probable equivalent of the marine Santa Barbara formation of southern California.

Santa Maria faunal zone (north of Point Conception, in the Santa Maria embayment, Santa Barbara County, lat. 35° N.). Arca trilineata Con., Cardium meekanum Gabb, Clidiophora punctata Carp., Dosinia ponderosa Gray, Glycimeris coalingensis Arn., Modiolus rectus Gld., Mya truncata L., Ostrea veatchi Gabb, Panomya ampla Dall, Pecten cf. cerrosensis Gabb, Pecten etchegoini And., Pecten hastatus Sby., Pecten healeyi Arn., Pecten hemphilli Dall, Pecten lawsoni Arn., Pecten oweni Arn., Pecten stearnsi Dall, Pecten wattsi Arn., Paphia stalevi Gabb. Paphia tenerrima Carp., Phacoides annulatus Rv., Thracia trapezoidea Con., Venericardia californica Dall, Argobuccinum oregonense Redf., Bathytoma carpenteriana Gabb, Cancellaria rapa Nomland, Cancellaria tritonidea Gabb, Chrysodomus portolaensis Arn., Crepidula princeps Con., Gyrineum elsmerense Eng., Miopleionia oregonensis Dall, Nassa californiana Con., Nassa moraniana Martin, Trochita radians Lam., Terebratalia occidentalis Dall, Dendraster ashleyi Arn.

This fauna contains a mixture of Fernando (southern) and Purisima-Wildcat (northern) species. It was the northern limit of Ostrea veatchi, Janira, Cancellaria tritonidea, and Gyrineum elsmerense. It was the southern limit of Cardium meekanum, Glycimeris coalingensis, Paphia staleyi, Nassa californiana, Nassa moraniana, and Miopleionia oregonensis.

It lacks: Ficus, Lyropecten, and Astrodapsis, which are characteristic of the more southerly contemporaneous Fernando. The temperature was probably a little warmer than that of the present Santa Barbara Channel (62° F. min.), and a little cooler than the present temperature south of Cerros Island (68° F. min.), which would make it approximately 64° F. Of the whole fauna 44% are extinct, and 56% living.

The age is that of the Fernando and the Purisima, upper part of lower Pliocene. At the base of the Santa Maria beds there occurs an horizon with the Etchegoin-Jacalitos fauna, including Pecten estrellanus, and Pecten coalingensis.

Etchegoin-Jacalitos. This fauna is found in the San Benito Valley, and on the west side of the San Joaquin Valley, south of San Francisco Bay, also at the bottom of the Fernando section of the Santa Maria embayment in Santa Barbara County. F. M. Anderson¹⁰, who first described the Etchegoin, assigned it to Pliocene, while R. Arnold11, who later published an account of both Etchegoin and Jacalitos, placed them in the upper Miocene. Dr. J. C. Merriam¹², correlates both Jacalitos and Etchegoin with Pliocene, basing his determination upon the relations of their vertebrate faunas with those of the continental Pliocene.

The recent study of the Etchegoin fauna by J. M. Nomland* places it beyond doubt that the Etchegoin and Jacalitos are practically identical, and that the joint fauna is Pliocene. There can also be little doubt that a portion of the Etchegoin overlaps with the Purisima. Collections by F. M. Anderson, R. Arnold, W. H. Ochsner, J. M. Nomland, and many others, have yielded the following fauna, along with many others not listed: Dendraster gibbsi Gabb, Dendraster perrini Weaver, Astrodapsis peltoides And. & Mart., Arca trilineata Con., Cardium coosense Dall, Cardium quadrigenarium Con., Chione elsmerensis Eng., Chione securis Shum., Cryptomya ovalis Con., Dosinia jacalitosana Arn., Glycimeris coalingensis Arn., Modiolus directus Dall, Mulinia densata Con., Mytilus coalingensis Arn., Ostrea atwoodi Gabb, Ostrea veatchi Gabb, Ostrea vespertina Con., Panopea generosa Gld., Paphia staminea Con., Paphia tenerrima Carp., Pecten cerrosensis Gabb, Pecten coalingensis Arn., Pecten estrellanus Con., Pecten etchegoini And., Pecten healeyi Arn., Pecten nutteri Arn., Pecten oweni Arn., Pecten proteus Nomland, Phacoides annulatus Rv., Placunanomia californica Arn., Schizothærus pajaroanus Con., Spisula albaria Con., Spisula coalingensis Arn., Thracia trapezoidea Con., Zirphæa dentata Gabb, Cancellaria rapa Nomland, Bathytoma carpenteriana Gabb, Bathytoma coalingaensis Arn., Callistoma coa-

 ¹⁹ A Stratigraphic Study in the Mount Diablo Range of California. <Proc. Calif. Acad. Sci. 3d Ser. Geol. Vol. 2, No. 2 (1905).
 ¹¹ Paleont. Coalinga District. Bull. 396, U. S. Geol. Survey (1909).
 ¹² Tertiary Vertebrate Faunas of the North Coalinga Region of California. <Trans. Amer. Phil. Soc. n. s. Vol. 22, Pt. 3 (1915), p. 29.

lingense Arn., Cancellaria tritonidea Gabb, Cancellaria rapa Nomland, Chrysodomus imperialis Dall, Chrysodomus portolaensis Arn., Ficus nodiferus Gabb, Miopleionia oregonensis Dall, Nassa californiana Con., Thais etchegoinensis Arn., Thais kettlemanensis Arn., Trophon coalingense Arn., Trophon ponderosus Gabb, Turritella vanvlecki Arn.

Of the entire fauna about 40% are living, and 60% extinct. The temperature was probably subtropical, as indicated by *Lyropecten*, *Ficus*, *Janira*, *Chione* of the *gnidia* group, and fluted *Ostrea*.

One good reason for placing the Etchegoin below the greater part of the Purisima zone is the fact that the Etchegoin fauna still preserves more of the warm water elements and has fewer of the boreal, Puget Sound, forms than the Fernando, although it lies 200 miles to the north. The isotherm of subtropical warmth had not yet moved to the south of Point Conception, as it had in the Fernando-Purisima epoch.

Near relationship between the Etchegoin-Jacalitos and the Purisima-Fernando is shown by the following species which range from Etchegoin into Purisima or Fernando, and are not known to occur higher in the section: Cardium meekanum, Chione elsmerensis, Chione securis, Cryptomya ovalis, Glycimeris coalingensis, Marcia oregonensis, Mulinia densata, Mytilus coalingensis, Paphia staleyi, Pecten healeyi, Pecten nutteri, Pecten wattsi, Pecten oweni, Spisula albaria, Venus pertenuis, Zirphea dentata, Cancellaria rapa, Chrysodomus imperialis, Chrysodomus portolaensis, Nassa moraniana, Polinices galianoi, Ficus nodiferus, Miopleionia oregonensis, Sinum scopulosum. In addition to these, the following are known to occur below the Etchegoin, and in the Purisima or Fernando horizon, but not yet known in the Etchegoin: Cardium coosense, Macoma astori, Miltha sanctæcrucis, Chrysodomus postplanatus, Trochita inornata. These are nearly all Miocene species ranging upward.

The Oriental group, *Pallium*, group of *Pecten swifti*, is especially abundant and characteristic in the Etchegoin fauna. The relationship of the American to the Japanese fauna becomes even more marked in the Purisima epoch, as it should, since the latter is more northern in position, and cooler in temperature than the Etchegoin.

TABLE OF PLIOCENE AND PLEISTOCENE OF SOUTHERN CALIFORNIA.

PLEISTOCENE	UPPER	Upper San Pedro, of San Pedro, San Diego, and many other points in the southern California embayment. Unconsolidated sands, several hundred feet thick, and gently tilted. Fauna with many tropical species.
PLEIS	Lower	Lower San Pedro, of San Pedro, Ventura and Santa Barbara, unconsolidated sands, somewhat more disturbed, with cold-temperate (Puget Sound) fauna.
	UPPER	Santa Barbara, of Santa Barbara, Dead Man Island, and many other places in the San Pedro region. Sands and clays slightly more disturbed, with cold-temperate (Puget Sound) fauna. These are the equivalent of the Santa Clara beds in middle California.
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PLIOCENE	Lower	Fernando, of Elsmere Canyon, Fernando Pass, Temescal Canyon, Third St. Tunnel in Los Angeles, Puente Hills, and the older beds in old San Diego, underlying the San Diego formation. The fauna is characterized by Ficus nodiferus, Lyropecten ashleyi, giant Conus, and Astrodapsis fernandoensis.
		Carrizo, of Carrizo Creek in Imperial County, and Cerros Island, Lower California. Fauna with Pecten veatchi, Pecten ashleyi, Pecten cerrosensis, Clypeaster bowersi, Encope tenuis, Dolium, giant Conus, Olivia porphyria, and reef-forming Astræidæ. This is the tropical equivalent of the Jacalitos-Etchegoin of middle California.

DIAGNOSTIC PLIOCENE SPECIES IN SOUTHERN CALIFORNIA

	Carrizo	Fernando	San Diego	Santa Barbara	Lower San Pedro	Upper San Pedro	Recent
Dendraster excentricus Esch " ashleyi Arnold Astrodapsis fernandoensis Eng Clypeaster bowersi Weaver Encope tenuis Kew. Terebratalia hemphilli Dall " smithi Arnold Arca trilineata Con " canalis Con " canuloensis Osmont Ostrea veatchi Gabb Pecten ashleyi Arnold " bellus Con " caurinus Gld	:::++::::++::	:++::++-+++:	++:::++++:+:++	+	+	+	+
" cerrosensis Gabb " healeyi Arnold " hemphilli Dall " jordani Arnold " keepi Arnold " oweni Arnold " opuntia Dall " parmaleei Dall " stearnsi Dall. " subnodosus Sby	+ : : : + : : : : +	+++::++:	+++:::+++:	+ + + +	+		Lower
Phacoides sanctæcrucis Arnold Cancellaria rapa Nomland Conus (giant) Ficus nodiferus Gabb " pyriformis Gabb Fusus barbarensis Trask Pisania fortis Carp Turritella jewetti Carp	 + 	+++++:+:		+++			Calif. +

Santa Barbara. The uppermost Pliocene in southern California, in the old Santa Barbara embayment from Point Conception to San Diego, has been called by various names, Merced, Fernando, and San Diego, but it is different in age and in fauna from all three. J. P. Smith¹³ proposed to call it the Santa Barbara zone, which term seems to be acceptable. The fauna of this horizon, from the beds at Santa Barbara, and Dead Man Island (San Pedro), chiefly collected and described

¹⁸ Geol. range of Miocene Invertebrate Fossils of California. <Proc. Calif. Acad. Sci. 4th Ser. Vol. 3, (1912), p. 169.</p>

by Ralph Arnold¹⁴, is as follows: Dendraster excentricus Esch., Terebratalia hemphilli Dall, Terebratalia smithi Arn., Marcia subdiaphana Con., Panopea generosa Gld., Pecten caurinus Gld., Pecten bellus Con., Pecten hastatus Sby., Pecten hericeus Gould, Pecten jordani Arn., Pecten opuntia Dall, Pecten stearnsi Dall, Thracia trapezoidea Con., Thyasira bisecta Con., Venericardia barbarensis Con., Venericardia ventricosa Gld., Argobuccinum oregonense Redf., Chrysodomus tabulatus Baird, Crepidula princeps Con., Fusus barbarensis Trask, Natica clausa B. & S., Pisania fortis Carp., Solariella peramabilis Carp., Tritonofusus rectirostris Carp., Trophon (Boreotrophon) gracilis Perry, Trophon (B.) stuarti Smith, Turris smithi Arn., Turritella jewetti Carp.

A census of the entire fauna shows about 15% extinct, and 85% living. The character is decidedly northern, with many Puget Sound types such as Pecten caurinus, Tritonofusus, and Chrysodomus, but with the southern Janira still persisting. The temperature was cooler than the present, and probably about the same as that of Puget Sound.

San Diego. This faunal zone, too, has been variously named, San Diego, Merced, and Fernando; but while it is the equivalent of the Merced, it is not synonymous with Fernando, and the name given by W. H. Dall¹⁵ antedates the others. formation is especially well developed at San Diego, Pacific Beach, San Pedro, Los Angeles, and Todos Santos Bay, Lower California. Collections by Henry Hemphill, R. Arnold, and many others, have yielded, among others: Dendraster ashlevi Arn., Terebratalia hemphilli Dall, Terebratalia smithi Arn., Arca canalis Con., Arca trilineata Con., Metis alta Con., Modiolus rectus Gld., Monia macroschisma Desh., Ostrea veatchi Gabb. Pecten bellus Con., Pecten caurinus Gld., Pecten cerrosensis Gabb, Pecten cooperi Arn., Pecten hastatus Sby., Pecten healeyi Arn., Pecten hemphilli Dall, Pecten opuntia Dall, Pecten parmaleei Dall, Pecten stearnsi Dall, Venericardia californica Dall, Chrysodomus tabulatus Baird, Tritonofusus rectirostris Carp.

¹⁴ Pal. and Stratig. Pliocene and Pleistocene of San Pedro, California, Mem. Calif. Acad. Sci. Vol. 3, (1903); The Tertiary and Quaternary Pectens of California, Prof. Paper No. 47, U. S. Geol. Survey, (1906); and New and characteristic species of fossil mollusks . . . Santa Barbara, etc. Smithson, Misc. Coll. Vol. 50, (1907); and New and characteristic species of fossil mollusks Southern California. Proc. U. S. Nat. Mus. Vol. 32, (1907), pp. 525-546.

¹⁴ Proc. Calif. Acad. Sci. Vol. 6, (1874), p. 227 et seq.; and A Table of North American Tertiary Horizons, etc., Eighteenth An. Rept. U. S. Geol. Survey, part 2, (1898), p. 337.

The most recent discussion of this fauna by C. L. Moody¹⁶,

adds greatly to the list of known species.

This horizon is the same as that of the Merced of middle California, but has more southern types, such as giant Arca, and Janira, and fewer northern forms. Of the whole fauna 30% are extinct, and 70% living. It is upper Pliocene, but not upppermost Pliocene. Moody correlates the Los Angeles fauna with the San Diego, but calls it Fernando, following the usage of Arnold.

Fernando. This name has been greatly misused, having come to be applied to all the Pliocene in southern California, and even the marine Pleistocene. G. H. Ashlev¹⁷ first listed the fauna, but merely called it the "beds at Fernando," without formally naming the geologic formation. Homer Hamlin first used the term, on unpublished maps, for the same beds from which came the fauna listed by Ashley. R. Arnold¹⁸ first published the name Fernando, but included in the formation the San Diego beds of the Los Angeles region, the Santa Barbara horizon of San Pedro and Santa Barbara, and some of the marine San Pedro Pleistocene of southern California.

W. A. English¹⁹ has used the term in its original significance, and described the true Fernando fauna.

Fernando fauna of southern California. The true Fernando, of Fernando Pass, Elsmere Canyon, Third St. Tunnel (Los Angeles), Temesal Canyon, and the Puente Hills, contains the following characteristic species: Astrodapsis fernandoensis Pack, Dendraster ashleyi Arn., Amiantis callosa Con., Arca canalis Con., Arca camuloensis Osmont, Arca grandis B. & S., Arca multicostata Sby., Arca trilineata Con., Cardium quadrigenarium Con., Chione elsmerensis Eng., Dosinia ponderosa Gray, Metis alta Con., Marcia subdiaphana Carp., Mya truncata L., Ostrea veatchi Gabb, Paphia tenerrima Carp., Pecten ashlevi Arn., Pecten bellus Con., Pecten cerrosensis Gabb, Pecten healeyi Arn., Pecten hemphilli Dall, Pecten oweni Arn., Pecten stearnsi Dall, Panopea generosa Gld., Phacoides sanctæcrucis Arn., Thyasira bisecta Con., Astræa undosa Wood,

¹⁶ Fauna of the Fernando of Los Angeles, Univ. of Calif. Pub. Bull. Dept. Geol. Vol. 10, No. 4, (1916), pp. 39-62.

¹⁷ The Neocene Stratigraphy of the Santa Cruz Mountains of Calif. Proc. Calif. Acad. Sci. 2d Ser. Vol. 5, (1895), pp. 273-367.

¹⁸ Bull, 309, U. S. Geol. Survey, p. 22.

¹⁹ The Fernando Group near Newhall, California, Univ. of Calif. Pub. Bull. Dept. Geol. Vol. 8, No. 8, (1914), pp. 203-218.

Calyptræa radians Lam., Cancellaria rapa Nomland, Cancellaria tritonidea Gabb, Conus species, Cypræa fernandoensis Arn., Ficus nodiferus Gabb, Ficus pyriformis Gabb, Murex eldridgei Arn., Pisania fortis Carp., Terebra martini Eng., Terebratalia occidentalis Dall, Terebratalia smithi Arn.

This decidedly indicates warm water, of a temperature not much below 68° F. min., not strictly tropical, for reef-forming corals are lacking, and there are several northern types that would hardly have lived in tropical waters. The abundant Lyropecten, Janira, Ficus, giant Arca and Miltha and the rarer Astrodapsis, Chione, Dosinia, Murex, and Cypræa, all speak for a temperature considerably higher than that now prevailing in the Santa Barbara Channel, or about 66° F. min. This fauna was the northern limit of Astrodapsis, Cypræa, giant Arca, Lyropecten, and Ficus, in the lower Pliocene. Of the whole fauna, as now known, about 50% are extinct, which agrees with that of the Santa Maria, the Purisima, and the Wildcat faunas.

Point Conception then played the part, now given to Cerros Island (Lower California), as the dividing line between the subtropical and the warm temperate zones. There was then considerable telescoping of the isotherms, since the cold-water belt came down to Cape Mendocino, and the warm temperate met the subtropical belt at Point Conception, with much more sharply defined climatic zones than now exist on the coast of California.

Carrizo (Imperial Co., Calif., and Cerros Island, Lower California, lat. 33° N.–28° N.). This fauna was first described by R. Arnold²⁰, who correlated it with the Etchegoin of middle California, a correlation which still stands. W. S. Kew²¹ has more recently described the fauna more fully, assigning it definitely to the Pliocene. The following forms are known to belong to the Carrizo: Arca (giant), Cardium quadrigenarium Con., Codakia cf. distinguenda Tryon, Metis alta Con., Ostrea palmula Carp., Ostrea veatchi Gabb, Ostrea heermani Con., Ostrea vespertina Con., Pecten carrizoensis Arn., Pecten ashleyi Arn., Pecten cerrosensis Arn., Pecten deserti Con., Pec-

²⁰ Science (n. s.), vol. 19, p. 503 (1904); and U. S. Geol. Survey, Prof. Paper No. 47, (1906).

²¹ Tertiary Echinoids of the Carrizo Creek region in the Colorado Desert. Univ. of Calif. Pub. Bull. Dept. Geol. vol. 8, No. 5, (1914).

ten keepi Arn., Pecten lecontei Arn., Pecten veatchi Gabb, Pinna species, Cassis species, Conus (giant), Cypræa species, Dolium (Malea) cf. ringens Swain., Oliva cf. porphyria L., Solarium species, Strombus cf. granulatus Gray, Turritella (giant), Cidaris species, Clypeaster bowersi Weaver, Clypeaster carrizænsis Kew, Clypeaster deserti Kew, Encope tenuis Kew, Mæandra bowersi Vaughan, Dichocænia merriami Vaughan, Plesiastræa californica Vaughan, Siderastræa californica Vaughan, Solenastræa fairbanksi Vaughan, Porites carrizensis Vaughan.

This is a thoroughly tropical fauna, all the species being nearly related to members of the Gulf or Panama fauna, with the exception of the Astræidæ, which indicate still warmer water than that of Panama. The Astræidæ are most nearly related to Caribbean forms, and suggest the possibility of a late Miocene connection between the Atlantic and the Pacific. There is nothing else in the fauna, however, to make this probable, T. W. Vaughan*, who has described the coral fauna of the Carrizo, leaves the question in abeyance. Further study by R. E. Dickerson has cast doubt upon the Pliocene age of the Carrizo fauna, and it may yet be placed in the Miocene, to which Arnold first assigned it.

It is clear that the real tropical belt extended up to Imperial County, California, lat. 33° N., the head of the ancient Gulf of California. The corals have not been found in the Carrizo formation on Cerros Island; it is probable that then, as now, the ocean side of Lower California was cooler than the Gulf in the same latitudes. The Carrizo beds of the Gulf were deposited in water that was probably considerably warmer than 68° F. min. temperature.

CLIMATIC DISTRIBUTION OF FAUNAS IN FERNANDO-PURISIMA EPOCH OF THE LOWER PLIOCENE.

I. Oregonian (Eel River, California, to Puget Sound, lat. 40°-49° N.). Cardium grænlandicum, Chione securis, Arca trilineata, Cardium meekanum, Pecten dilleri, Pecten caurinus, Spisula albaria, Spisula voyi, Saxidomus giganteus, Thyasira bisecta, Dendraster oregonensis Clark. The present temperature

^{*} The reef-coral fauna of Carrizo Creek, etc. U. S. Geol. Survey, Prof. Paper No. 98-T, pp. 353-395, 1917.

of the sea is 50° F. min., and the fossil fauna indicates about the same temperature.

- II. Franciscan or Middle Californian (Cape Mendocino to Pt. Conception, 40°-34° 30′ N.). Chione securis, Cardium meekanum, Peronidea lutea Gray, Spisula albaria, Chrysodomus imperialis, C. purisimaensis, C. stantoni, C. tabulatus, Priene pacifica, Argobuccinum oregonense, Gyrineum marshalli, Miopleionia oregonensis, Scutella interlineata, (all northern species); Dosinia ponderosa, Arca trilineata, Arca canalis, Chione elsmerensis, Pecten healeyi, Pecten nutteri, Pecten oweni, Dendraster ashleyi, (all southern species). This fauna lacks: Ficus, Janira, Lyropecten, Astrodapsis, Trachycardium, giant Conus, Amiantis, and the Arca multicostata group. The temperature was about 60° F.
- III. Fernandan, or Southern Californian (Pt. Conception to San Diego, 34° 30′-33° N.). Ficus nodiferus, Dosinia ponderosa, Arca camulosensis, Arca multicostata, Arca grandis, Chione, Lyropecten, Trachycardium, Amiantis, Pecten healeyi, Janira; Pecten hemphilli, P. stearnsi; giant Conus, Cypræa, Cancellaria, Dendraster ashleyi, Astrodapsis fernandoensis, (all southern species, indicating a minimum temperature of at least 65° F., several degrees warmer than the present, which has a minimum of about 62° F.).
- IV. Gulf of California. The equivalent of the Fernando fauna is not yet known in Lower California, but the next lower fauna, the Carrizo, is decidedly tropical, and indicates a minimum temperature of not less than 68° F.

MIOCENE

Shumagin Islands (off the Alaskan Peninsula, lat. 55° N.). This is the most northerly Miocene known on the American coast; it has been described by W. H. Dall²², who assigns it to lower Miocene, on the basis of identity of a few species with those of the lower Miocene of Oregon. The species listed by Dall are: Cardium ciliatum Fab., Cardium decoratum Gren., Glycimeris kochevarofi Gren., Mytilus middendorffi Gren., Paphia grewingki Dall, Papyridea harrimani Dall, Mya aren-

²² Harriman Alaska Exped. vol. 4, (1904). Neozoic invertebrate fossils, pp. 111-120...

aria L., Mya crassa Gren., Mya truncata L., Pecten fucanus Dall, Saxicava ungana Gren., Buccinum sp., Chrysodomus cf., liratus Martyn, Tritonofusus sp.

This fauna is decidedly northern, very like that of the Alaskan Gulf and Puget Sound region. It seems to the writer more likely to be the boreal equivalent of the Puget Sound Empire fauna. There are too many Recent species in it for it to be equivalent to either the Astoria (Oligocene), or the Clallam (lower Miocene) of Oregon and Washington.

Empire. On the shores of Oregon and Washington, from Cape Blanco (lat. 42° 50' N.) to the Olympic Peninsula, (lat. 48° N.), occurs the Empire formation. It was described by W. H. Dall ²³, as upper Miocene, his fossils having been collected at Coos Bay, Oregon, by B. H. Camman, from the entire section exposed there. This fauna has since been collected and described by R. Arnold and H. Hannibal ²⁴ at Coos Bay, and numerous other localities up to the Olympic Peninsula. Collections by B. H. Camman and H. Hannibal have yielded: Arca trilineata Con., Cardium coosense Dall, Cardium meekanum Gabb, Chione securis Shum., Glycimeris grewingki Dall, Macoma astori Dall, Macoma calcarea Gmel., Marcia oregonensis Con., Mulinia densata Con., Mya truncata L., Mytilus middendorffi Gren., Nucula conradi Meek, Panomya ampla Dall, Paphia staleyi Gabb, Pecten coosensis Dall, Phacoides acutilineatus Con., Schizothærus pajaroanus Con., Spisula albaria Con., Tellina aragonia Dall, Argobuccinum cammani Dall, Argobuccinum coosense Dall, Bathytoma gabbiana Dall, Boreotrophon stuarti Smith, Bullia bogachieli Rgn., Calyptræa bairdi Dall, Cancellaria oregonensis Dall, Chrysodomus bairdi Dall, Chrysodomus imperialis Dall, Crepidula princeps Con., Cymatium pacificum Dall, Fusus coosensis Dall, Miopleionia oregonensis Dall, Natica clausa B. & S., Phalium æquisulcatum Dall, Phalium turricula Dall, Polinices galianoi Dall, Turris coli Dall, Turris perversa Gabb, Discinisca oregonensis Dall, Dendraster gabbi Rémond. Dall also lists Eudolium oregonense Dall, but it seems more likely that this, possibly along with Phalium æquisulcatum, and P. turricula came out of the older Astoria or Clallam beds, since the fossils were collected on

²³ U. S. Geol. Survey, Prof. Papers No. 59, (1909), ²⁴ The marine Tertiary stratigraphy of the north Pacific Coast of America. Proc. Amer. Phil. Soc. vol. 52, No. 212, (1913), pp. 559-605.

the beach, without discrimination. The Empire fauna, as here listed, seems to be an incongruous mixture of the Purisima-Wildcat fauna with a few adventitious forms out of either the Astoria (Oligocene), or the Clallam (lower Miocene). If the Empire does represent an independent horizon, it can correspond only to the lost interval between the Monterey and the Santa Margarita-San Pablo of the California section.

Clallam (Olympic Peninsula, Washington, lat. 48° N.). The Clallam formation was first described by R. Arnold, 25 as the equivalent of the Monterey of the Californian section, and this correlation still stands. A portion of this fauna has since been described by W. H. Dall,26 and fuller lists have been given by Arnold and Hannibal,27 but with the inclusion of some Oligocene elements. C. E. Weaver,28 has also described a portion of this fauna. Other species have been added by F. M. Anderson and Bruce Martin.29 All these writers agree in correlating the Clallam with the Monterey. Characteristic species, collected by these various workers are: Arca devincta Con., Arca trilineata Con., Dosinia mathewsoni Gabb, Leda tenita Con., Marcia oregonensis Con., Panopea generosa Gld., Pecten fucanus Dall, Pecten propatulus Con., Phacoides acutilineatus Con., Spisula albaria Con., Tellina arctata Con., Tellina obruta Con., Tellina oregonensis Con., Thracia trapezoidea Con., Thyasira bisecta Con., Venus clallamensis Rgn., Yoldia impressa Con., Yoldia oregona Shum., Ampullina oregonensis Dall, Chrysodomus nodiferus Con., Crepidula prærupta Con., Cylichnella petrosa Con., Ficus clallamensis Weaver, Fusus devinctus Con., Fusus corpulentus Con., Fusus geniculus Con., Miopleionia indurata Con., Natica oregonensis Con., Polinices saxea Con., Sinum scopulosum Con., Turritella oregonensis Con.

Most of these forms are also found in the Monterey-Temblor of California; but the Clallam fauna lacks Lyropecten. Conus, giant Turritella, and Scutella (southern types). It indicates warm temperate conditions, but cooler than the contemporary Monterey-Temblor of California.

²⁵ A geological reconnaissance of the Olympic Peninsula. Bull. Geol. Soc. Amer. vol.
17, (1906), pp. 451-468.
²⁰ Prof. Paper No. 59, U. S. Geol. Survey, (1909).
²¹ Proc. Amer. Phil. Soc. vol. 52, No. 212, (1913), pp. 586-588.
²³ A preliminary report on the Tertiary paleontology, Washington Geol. Survey,
Bull. No. 15, (1912), pp. 1-80.
²⁰ Neocene record in the Temblor basin, California, etc. Proc. Calif. Acad. Sci. 4th ser. vol. 4, 1914), pp. 15-112.

Santa Margarita-San Pablo. This fauna is found throughout the inner Coast Ranges of middle California, from Mt. Diablo southward to the Coalinga region. Since the classic works of Conrad and Gabb, it has been described by R. Arnold,³⁰ from the Salinas Valley and the Coalinga region of the San Joaquin Valley; and by numerous writers upon the region of Mt. Diablo, especially B. L. Clark,³¹ who has published a monograph on the entire San Pablo fauna.

The most important species in the Santa Margarita-San Pablo fauna are: Asterias remondi Gabb, Astrodapsis antiselli Con., Astrodapsis tumidus Rémond, Astrodapsis whitnevi Rémond, Clypeaster brewerianus Gabb, Dendraster gibbsi Gabb, Dendraster gabbi Rémond, Discinisca oregonensis Dall, Tamiosoma gregaria Con., Amiantis dalli Clark, Arca microdonta Con., Arca trilineata Con., Cardium californiense Desh., Cardium meekanum Gabb, Cardium quadrigenarium Con., Chione diabloensis Clark, Chione pabloensis Clark, Chione securis Shum., Dosinia arnoldi Clark, Dosinia merriami Clark, Dosinia ponderosa Gray, Glycimeris coalingensis Arn., Macoma andersoni Clark, Macoma pabloensis Clark, Marcia oregonensis Con., Modiolus gabbi Clark, Mulinia densata Con., Mytilus coalingensis Arn., Ostrea attwoodi Gabb, Ostrea titan Con., Panopea estrellana Con., Paphia tenerrima Carp., Pecten crassicardo Con., Pecten estrellanus Con., Pecten holwayi Clark, Pecten pabloensis Con., Pecten raymondi Clark, Pecten sancti-ludovici And., Pecten weaveri Clark, Phacoides annulatus Rv., Pinna alamedensis Yates. Pitaria stalderi Clark, Spisula albaria Con., Spisula lenticularis Gabb, Tellina diabloensis Clark, Tivela gabbi Clark, Agasoma sinuatum Gabb, Astralium raymondi Clark, Cancellaria pabloensis Clark, Calyptræa filosa Gabb, Calyptræa inornata Gabb, Chrysodomus diabloensis Clark, Chrysodomus imperialis Dall, Gyrineum trampasense Clark, Ficus nodiferus Gabb, Hemifusus dalli Clark, Neverita recluziana Petit, Siphonalia kellettii Fbs., Trophon carisaenses And., Trophon ponderosus Gabb, Turritella vanvlecki Arn.

⁸¹ Fauna of the San Pablo group of middle California, Univ. of Calif. Pub. Bull., Dept. Geol., vol. 8. No. 22, (1915), pp. 385-570.

⁸⁰ The Tertiary and Quaternary Pectens of California. Prof. Paper No. 47, U. S. Geol. Survey, (1906); and Paleontology of the Coalinga District, etc. Bull. 396, U. S. Geol. Survey, (1909).

This fauna is of upper Miocene age, and probably represents the whole of that epoch. It has about 25 per cent of Recent species, and 75 per cent extinct. The abundant Lyropecten, giant Ostrea, Astrodapsis, Trophon, Ficus, and Dosinia indicate subtropical conditions as far north as Mt. Diablo in middle California. North of that locality the fauna is unknown.

Monterey-Temblor. Since the work of Conrad in the Pacific Railroad Reports, and of Gabb in the Palæontology of California, vol. 2, many workers have contributed to the knowledge of the Monterev fauna. Among them have been: Frank M. Anderson, 32 who has devoted himself especially to the study of the Temblor phase of the Miocene of the middle Coast Ranges and The Kern River deposits near Bakersfield; R. Arnold. 33 who has given special attention to the fauna in the oil fields of the southwestern part of the San Joaquin Valley, and of southern California. Anderson, in his various papers, has called this fauna the Temblor, while Arnold has called it Vagueros. Most workers in West Coast stratigraphy are now agreed that the Temblor fauna is not synchronous with the Vaqueros, but does agree with the Monterey, upper part of, lower Miocene.

The most important species of the Monterey-Temblor are: Scutaster andersoni Pack, Scutella fairbanksi Arnold, Scutella merriami Anderson, Scutella norrisi Pack, Linthia californica Weaver, Arca devincta Con., Arca microdonta Con., Arcaobispoana Con., Arca trilineata Con., Amiantis conradiana And., Amiantis diabloensis And., Cardium quadrigenarium Con., Cardium vaguerosense Arn., Chione mathewsoni Gabb. Chione panzana And., Corbicula dumblei And., Dosinia conradi Gabb, Dosinia matherosoni Gabb, Dosinia ponderosa Gray, Glycimeris branneri Arn., Macoma ocoyana Con., Macoma arctata Con., Marcia oregonensis Con., Metis alta Con., Modiolus multiradiatus Gabb, Mulinia densata Con., Mytilus expansus Arn., Nucula conradi Meek, Ostrea eldridgei Arn., Ostrea titan Con., Panopea estrellana Con., Panopea generosa

⁸² A stratigraphic study in the Mount Diablo Range of California, Proc. Calif. Acad. Sci., Third Ser. Geol., vol. 2, No. 2, 1905, pp. 156-248; The Neocene deposits of Kern River, etc. Proc. Calif. Acad. Sci., 4th Ser., vol. 3, (1911), pp. 73-148; and Anderson and Martin, Neocene record in the Temblor basin, etc., Proc. Calif. Acad. Sci., 4th Ser. Vol. 4, pp. 15-112 (1914).

⁸³ Bull. 309, U. S. Geol. Survey, (1907); Prof. Paper No. 47, U. S. Geol. Survey, (1906) Bull. 322, U. S. Geol. Survey (1907); Bull. 396, U. S. Geol. Survey (1909); and Descr. New Cretaceous and Tertiary fossils, etc., Proc. U. S. Nat. Mus., vol. 34, No. 1617, (1908), pp. 343-389.

Gld., Pecten andersoni Arn., Pecten crassicardo Con., Pecten discus Con., Pecten estrellanus Con., Pecten hamlini Arn., Pecten lompocensis Arn., Pecten miguelensis Arn., Pecten nevadanus Con., Pecten peckhami Gabb, Pecten perrini Arn., Pecten propatulus Con., Phacoides acutilineatus Con., Phacoides richthofeni Gabb, Phacoides sanctæcrucis Arn., Pinna alamedensis Yates, Septifer coalingensis Arn., Tellina idæ Dall, Thracia trapezoidea Con., Tivela inezana Con., Yoldia impressa Con., Yoldia oregona Shum., Yoldia submontereyensis Arn., Zirphea dentata Gabb, Agasoma barkerianum Cooper, Bathytoma kecpi Arn., Cancellaria condoni And., Cancellaria dalliana And., Cancellaria vetusta Gabb, Chrysodomus nodiferus Con., Conus hayesi Arn., Conus owenianus And., Crepidula princeps Con., Ficus kernianus Cooper, Ficus nodiferus Gabb, Ficus pyriformis Gabb, Hemifusus wilkeseanus And., Macron merriami Arn., Molopophorus anglonana And., Nassa arnoldi And., Neverita callosa Gabb, Ranella mathewsoni Gabb, Sinum scopulosum Con., Terebra cooperi And., Thais præcursor Dall, Trochita costellata Con., Trophon carisaensis And., Trophon gabbianus And., Trophon kernensis And., Turritella ocovana Con.

This faunal horizon has been called by Dr. J. C. Merriam the *Agasoma* zone, but this name is given up, since the genus *Agasoma* is not confined to the zone; and the original Agasoma beds have been shown by Dr. B. L. Clark to be Oligocene.

This fauna is tropical or subtropical, and indicates a temperature considerably warmer than that of southern California at present, as shown by the presence of *Chione, Dosinia, Lyropecten*, giant *Arca, Ficus, Trophon, Conus, Pinna*, and giant *Turritella*, all tropical types.

Vaqueros. This formation was first named by H. W. Fairbanks, ³⁴ from the outer Coast Ranges, in the region of San Luis Obispo, California. It was afterwards recognized by R. Arnold³⁵ at numerous localities in the outer Coast Ranges of middle California, and in the Santa Ynez Mountains of southern California.

⁸⁴ U. S. Geol. Survey, San Luis Folio (1904), No. 101.
⁸⁵ Prof. Paper 47, U. S. Geol. Survey, (1906); Bull. 309, U. S. Geol. Survey, (1907); Proc. U. S. Nat. Mus., vol. 34, No. 1617, (1908), pp. 343-389; and Environment of the Tertiary faunas of the Pacific Coast of the United States, Jour. Geol., vol. 17, (1909), pp. 509-533.

The most important species, so far as known, are: Scutella fairbanksi Arn., Scutella norrisi Pack, Terebratalia kennedyi Dall. Astræa biangulata Gabb, Dosinia conradi Gabb, Dosinia whitneyi Gabb, Glycimeris branneri Arn., Modiolus ynezanus Arn., Mytilus expansus Arn., Panopea generosa Gld., Pecten branneri Arn., Pecten lompocensis Arn., Pecten magnolia Con., Pecten nevadanus Con., Pecten perrini Arn., Pecten sanctæcruzensis Arn., Pecten sespeensis Arn., Pecten vanvlecki Arn., Tivela inezana Con., Natica inezana Con., Rapana vaquerosensis Arn., Trochita costellata Con., Turritella inezana Con.

This fauna is lower Miocene, and represents the very bottom of that series. The abundant Lyropecten, giant Turritella, Dosinia, Chione, and Rapana indicate tropical or subtropical conditions. The Vagueros has not been found to the north of middle California.

Of this fauna, Lyropecten, Dosinia, and Chione are immigrants from the Caribbean; the Turritella group is a little modified descendant of the Eocene giants; Rapana can only have come from the southern Orient, from the same source as Miopleionia, and Amusium.

What appears to be a Vagueros fauna has been collected by Mr. E. C. Brown on the Pacific coast of Lower California, near San Gregorio Lagoon, lat. 26° N. It contained Lyropecten, giant Turritella, and Rapana.

OLIGOCENE.

Astoria. The Astoria, Oligocene, fauna has been collected at various places on the Pacific Coast, from the Santa Cruz Mountains, lat. 37° N., to the Olympic Peninsula, lat. 48° N. It has been described from Oregon by W. H. Dall, 36 and from both Washington and Oregon by Arnold and Hannibal.37 C. E. Weaver³⁸ has also described species of this fauna from the coast of Washington; and R. Arnold³⁹ has described the species known to occur in the equivalent San Lorenzo formation in the Santa Cruz Mountains of middle California.

 ⁸⁶ Prof. Paper No. 59, U. S. Geol. Survey (1909).
 87 Proc. Amer. Phil. Soc., vol. 52, No. 212 (1913), pp. 559-605.
 83 Washington Geol. Survey, Bull. No. 15, (1912); and Univ. of Washington Pub. in Geol., vol. 1, No. 1, pp. 1-67 (1916).
 89 Proc. U. S. Nat. Mus., vol. 34, pp. 345-390, (1908).

The most important species thus far known are: Cardium lorenzoanum Arn., Crenella porterensis Weaver, Dosinia matheresoni Gabb, Macrocallista matheresoni Gabb, Macrocallista vespertina Con., Macoma nasuta Con., Marcia oregonensis Con., Mytilus mathewsoni Gabb, Mytilus ynesianus Arn., Nucula gettysburgensis Rgn., Nucula townsendi Dall, Panopea generosa Gld., Pecten branneri Arn., Pecten waylandi Arn., Phacoides acutilineatus Con., Solemya ventricosa Con., Spisula albaria Con., Tellina lorenzoensis Arn., Thracia trapezoidea Con., Thyasira bisecta Con., Yoldia impressa Con., Yoldia oregona Shum., Agasoma gravidum Gabb, Crepidula prærupta Con., Eudolium petrosum Con., Fusus hecoxi Arn., Miopleionia indurata Con., Molopophorus gabbi Dall, Strepsidura oregonensis Dall, Turcicula washingtoniana Dall, Turritella newcombei Merriam, Turritella oregonensis Con., Aturia angustata Con.

These forms indicate tropical or subtropical waters, which extended up at least as far north as Puget Sound. Noteworthy is the appearance of the first Recent species: Panopea generosa Gld., Macoma nasuta Con., Thracia trapezoidea, and Thyasira bisecta Con. The others are all extinct, but many have living relatives in warm latitudes, especially Aturia and Eudolium. There are no apparent relations with the Caribbean Oligocene, the Panama portal having probably been closed at this time. An immigration from the Orient is shown by the presence of Dolium, Voluta (Miopleionia), and other forms with near relatives still living in that region.

EOCENE.

Tejon. The upper Eocene, Tejon, fauna of California has recently been described in monographic form by R. E. Dickerson, 40 so that it is unnecessary to give further references. This same fauna extended unchanged to Puget Sound, and Venericardia planicosta, the "finger-post of the Eocene", reached up to Alaska. 41

The most characteristic species of this horizon are: Balanophyllia striata Gabb, Flabellum remondianum Gabb, Trocho-

⁴⁶ Stratigraphy and fauna of the Tejon Eocene of California Univ. of Calif. Pub. Bull., Dept. of Geol. vol. 9, No. 17, (1916), pp. 363-524.

⁴¹ W. H. Dall, Harriman Alaska Exped. Neozoic Invert. fossils, p. 103.

cyathus stantoni Vaughan, Cassidulus californicus And., Schizaster lecontei Merriam, Avicula pellucida Gabb, Arca morsei Gabb, Crassatellites collina Con., Crassatellites grandis Con., Crassatellites uvasana Con., Cucullæa morani Waring, Cardium breweri Gabb, Cardium cooperi Gabb, Dosinia elevata Gabb, Glycimeris sagittata Gabb, Macrocallista californica Con., Macrocallista horni Gabb, Macrocallista uvasana Con., Ostrea idriaensis Gabb. Spisula merriami Packard. Tellina remondi Gabb, Venericardia merriami Dickerson, Venericardia planicosta Lam., Amauropsis alveata Con., Architectonica cognata Gabb, Conus californiana Con., Conus horni Gabb, Ficopsis cowlitzensis Weaver, Ficopsis horni Gabb, Ficus mamillatus Gabb, Galeodea sutterensis Dickerson, Galeodea tuberculata Gabb, Gyrineum washingtonianum Weaver, Loxotrema turrita Gabb, Lunatia horni Gabb, Lyria andersoni Waring, Murex sopenahensis Weaver, Natica hannibali Dickerson, Olivella mathewsoni Gabb, Perissolax blakei Gabb, Rimella canalifera Gabb, Rimella simplex Gabb, Siphonalia sutterensis Dickerson, Terebellum erraticum Cooper, Terebra californica Gabb, Tritonium californicum Gabb, Turris fresnoensis Arn., Turritella merriami Dickerson, Turritella uvasana Con, Nautilus sp.

This is a decidedly tropical fauna, with Nautilus, Macrocallista, giant Venericardia, Crassatellites, Conus, Ficus, Fusus, giant Turritella, Rimella, and Galcodea all represented in the tropics by kindred forms. This tropical belt extended up to Puget Sound, and the Alaskan waters were probably cooler.

The Tejon fauna is of Caribbean origin, and the zone of *Venericardia planicosta* represents the last great migration from the Atlantic to the Pacific. Many Tejon species are identical with, or closely related to, forms in the Eocene of the Gulf states.

Kenai flora (Unga Island, Shumagin Islands, Alaskan Peninsula, lat. 55° N.). This flora was listed by W. H. Dall⁴² as Oligocene, while A. H. Brooks⁴³ considers it as Eocene. The forms known are: Taxodium distichum miocenicum Hr., Glyptostrobus europæus Hr., Sequoia nordenskioldi Hr., Quercus pseudocastanea Gpt., Castanea ungeri Hr., Populus glandifer Al. Br., Liquidambar europæum Al. Br., Betula, Alnus,

Seventeenth An. Rept., U. S. Geol. Survey, Part 1, (1896), p. 836.
 Prof. Paper No. 45, U. S. Geol. Survey, (1906), p. 238.

Carpinus, Corylus, Fagus, Ulmus, Planera, Nyssa, Viburnum, Diospyros, Vaccinium, Vitis, Cornus, Magnolia, Acer, Juglans.

This flora indicates warm temperate conditions, about the same as the South Atlantic states.

Ione Flora (middle California, in the inner Coast Ranges, and in the Auriferous Gravels, Sierra Nevada). Acer æquidentatum Lx., Aralia angustiloba Lx., Aralia whitneyi Lx., Castanea castaneæfolia Ung., Castaniopsis chrysophylloides Lx., Cornus hyperborea Hr., Ficus tiliæfolia Al. Br., Juglans californica Lx., Juglans laurinea Lx., Geonomites schimperi Lx., Liquidambar californicum Lx., Magnolia californica Lx., Magnolia lanceolata Lx., Persea pseudocarolinensis Lx., Platanus appendiculata Lx., Quercus nevadensis Lx., Quercus distincta Lx., Rhus myricæfolia Lx., Sabalites californica Lx., Ulmus affinis Lx., Ulmus californica Lx., Zizyphinus piperoides Lx.

This flora is certainly tropical, or subtropical, and extends with little change up to Puget Sound, where palms are more abundant than they are in the Ione flora.

The flora of the Auriferous Gravels (Ione) was listed by F. H. Knowlton⁴⁴ as Miocene. This does not agree with the results of various workers on the West Coast, and R. E. Dickerson⁴⁵ has proved conclusively that the Ione portion of the Auriferous Gravels is Eocene. This flora has been found interbedded with marine Eocene forms in the Mt. Diablo region in the Coast Ranges, in the foothills of the Sierra Nevada, of California, and in the Arago Eocene of Oregon.

Martinez fauna. The Martinez is the oldest Eocene known on the Pacific Coast; its fauna has been described in monographic form by R. E. Dickerson. Species are: Terebratalia tejonensis Stanton, Flabellum remondianum Gabb, Trochocyathus zitteli Merriam, Cucullæa mathewsoni Gabb, Crassatellites unioides Stanton, Glycimeris veatchi Gabb, var. major Stanton, Leda alæformis Gabb, Leda packardi Dickerson, Lima multiradiata Gabb, Lima haseltinei Dickerson, Lima perrini Waring, Pecten interradiatus Gabb, Phacoides turneri Stanton, Pholadomya nasuta Gabb, Tellina undulifera Gabb, Venericardia planicosta var. venturensis Waring, Architectonica tabulata

 ⁴⁴ Prof. Paper No. 73, U. S. Geol. Survey, (1911), pp. 57-64.
 45 Univ. of Calif. Pub. Bull. Dept. Geol., vol. 9, No. 17, (1916), pp. 409 et seq.
 46 Fauna of the Martinez Eocene of California. Univ. of Calif. Pub. Bull. Dept. Geol., vol. 8, No. 6, (1914), pp. 61-180.

Weaver, Brachysphingus liratus Gabb, Heteroterma gabbi Stanton, Neptunea mucronata Gabb, Ovula martini Dickerson, Perissolax blakei Con., Turbinella crassitesta Gabb, Turritella maccreadyi Waring, Turritella martinezensis Gabb, Turritella pachecoensis Stanton, Turritella simiensis Waring, Urosyca caudata Gabb, Urosyca robusta Weaver, Xenophora zitteli Weaver, Hercoglossa merriami Dickerson, Nautilus stephensoni Dickerson, Nautilus hallidayi Waring.

The Martinez horizon is not yet known north of California, but it is certain that tropical conditions extended at least that far north at this time, and probably much further. No flora of this age is known, but one is not needed to tell us the climatic conditions.

SUMMARY.

In the Eocene there is no suggestion of climatic zones, the marine faunas being nearly the same from the equator to Alaska. The fossil floras of California, Oregon, and Washington indicate tropical conditions on the land.

In the Oligocene, tropical types, *Aturia* and *Dolium*, ranged up to Puget Sound. Marine beds of this age are not yet known in Alaska, but the Kenai flora belongs to the warm temperate zone.

In the lower Miocene the Californian faunas are tropical, and *Ficus*, a tropical genus, occurs in the Clallam fauna of Washington. It is not known whether the warm belt extended up to Alaska, for lower Miocene faunas and floras are not yet described from there.

In the middle Miocene, (Empire), *Phalium*, a tropical genus, is found in the region of Puget Sound, but there is a great increase in the number of giant *Chrysodomus*, suggesting a lowering temperature.

The Santa Margarita-San Pablo, upper Miocene, with giant Ostrea, numerous Trophon, Lyropecten and Astrodapsis, shows that the climate was still subtropical in California. Faunas of this age are not known in the Puget Sound region, while those of the Alaskan Gulf indicate cooler water. On the Asiatic side of the Pacific the warm belt extended to northern Siberia, for Dall⁴⁷ has described from there a subtropical fauna.

⁴⁷ A subtropical Miocene fauna in arctic Siberia, Proc. U. S. Nat. Mus., vol. 16, (1893), pp. 471-478.

The Jacalitos-Etchegoin, upper Miocene or lower Pliocene, in middle California, still retains *Ficus*, *Lyropecten*, *Janira*, and tropical types of *Ostrea*. The contemporary Carrizo fauna of the head of the old Gulf of California is much more decidedly tropical, with *Clypeaster*, *Dolium*, and Astræidæ.

In the Fernando-Purisima epoch of the lower Pliocene climatic zones are already definitely established. The faunas of this age from near Cape Mendocino, (Wild cat), and Puget Sound, contain *Pecten caurinus*, numerous giant *Chrysodomus*, *Buccinum*, *Volutopsius*, and indicate a temperature colder than the present in those latitudes.

The Purisima of middle California contains a few of the giant *Chrysodomus*, and other northern types, but has also many southern forms, such as *Dosinia*, *Chione elsmerensis*, *Pecten healeyi*. Cape Mendocino was then the dividing line between the northern and the southern faunas, just as Pt. Conception is now.

The Fernando of southern California has Ficus, Janira, Lyropecten, giant Conus and Astrodapsis, tropical forms lacking in the Purisima, indicating a milder temperature than that of the present Santa Barbara Channel.

In the Merced epoch the Puget Sound climatic zone has shifted south of Cape Mendocino, and some of the northern forms range down to the San Diego formation of Los Angeles and San Diego (*Pecten caurinus*), although the large numbers of *Janira* and *Ostrea veatchi* in the San Diego indicate a temperature nearly as warm as the present.

In the upper Pliocene Santa Barbara fauna, of Santa Barbara and San Pedro, the almost total extinction of southern types, and the prevalence of a Puget Sound fauna, indicate a sea temperature not higher than 50° F. min. Whether this chilling by the oncoming Glacial Epoch was felt south of California is not known.

The lower Pleistocene (lower San Pedro) shows the entire coast, from Alaska to San Diego, in the grip of the cold northern climate, a southward shifting of the isotherms of at least a thousand miles, and a general lowering of temperature by about 12° F., as far south as Los Angeles.

This shifting of the isotherms was felt as far southward as Magdalena Bay, Lower California, in the edge of the tropics, for the Quaternary fauna of that locality, while still tropical, contains many Californian species not known to occur there now.

This was the time of greatest southward shifting of the isotherms and greatest lowering of temperature on the West Coast. It probably corresponds to the maximum glaciation on the continents of the northern hemisphere.

A very decided rebound from the cold temperate conditions of the lower Pleistocene is seen in the fauna of the upper San Pedro formation in the Los Angeles embayment of southern California. This fauna shows a displacement of all the northern types, and the incoming of tropical forms from Lower California; among them are: Dosinia ponderosa, Pecten subnodosus, Chione gnidia, Chione neglecta, Cardium procerum, Miltha childreni. This would indicate a minimum temperature of nearly 68° F., a rise of about 18° F. from the lower San Pedro.

This amelioration of the climate extended up to Cape Nome, for there the fossil fauna contains *Pecten swifti*, which now lives 1200 miles to the southwest in the Japanese waters, warmer by 8° F. than the present temperature of Bering Sea.

The two extremes of climatic conditions are seen in the Eocene and in the lower Pleistocene. In the former a tropical climate extended up to Alaska, and in the latter a Puget Sound climate stretched southward to San Diego.

The fall and the rise were probably oscillatory rather than regular, but the marine faunas do not furnish a sufficiently sensitive thermometer to register the minor fluctuations.

Basis of the Work.

The conclusions given in this paper are based upon a critical study of collections of Recent, Quaternary, and Tertiary fossils made on the Pacific Coast, from Ecuador to Alaska. Material was studied by the writer, or by workers assisting him, in the U. S. National Museum, Philadelphia Academy of Science, California Academy of Sciences, University of California,

Stanford University, University of Oregon, and University of Washington.

The most important works used in this study are given in the appended bibliography, though many others, not cited, were consulted.

The classic writings of Carpenter, Gould, and Cooper on the Recent Mollusa gave the groundwork for the investigation. The pioneer works of Conrad and Gabb on Tertiary fossils gave the basis for comparison of Recent and Tertiary faunas. This was amplified by detailed study of the later literature, especially of Dall on the Recent and Tertiary faunas, and of Arnold on the Tertiary of California. Also the papers of Weaver on the Tertiary faunas of Washington have been invaluable, in determining the horizons of the Puget Sound region, and comparing them with those of California.

The writings of Dall, Arnold, Anderson, Hannibal, Dickerson, B. L. Clark, C. A. Waring, J. M. Nomland, and many others, on Tertiary geographic conditions on the West Coast, have changed many of our old ideas on the subject, and necessitated much revision.

It has been the aim of the writer to bring the information on the subject up to date, and to formulate results of his own studies as well as those of the other workers in the stratigraphy and paleontology of California.

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